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The Intuitive Bioclimatism and Embedded Sustainability of Cypriot Vernacular Farmhouses, as Principles for their Strategic Restoration and Reuse.

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Abstract. This research aims to investigate the bioclimatic design, sustainability and environmental behaviour of Cypriot vernacular farmhouses, as part of small-scale family-owned farmsteads. These farmhouses, located in village outskirts, are still in operation, greatly supporting the primary sector of Cypriot economy. Current uses have conduced arbitrary modifications in their morphology, layout, construction and usage, which in the past had contributed positively to thermal comfort and household autonomy. In the present, these modifications caused farmhouses to become climatically inept, devoid of Bioclimatism and Sustainability. This research employs multiple case studies with a fully-integrated mixed-methods design. Findings are drawn via triangulation of qualitative and quantitative data from ethnographic participant observation, post-occupancy evaluation survey, interviews, in-situ documentation and environmental monitoring. Initial findings show that there is a tangible and intangible relationship between the dwelling, its inhabitants and the environment, strengthened in time due to tradition, accumulated knowledge and experience, and born out of necessity, scarcity and practicality. It is an interdependent, dynamic and adaptive reciprocity, induced by the complex interplay of socio-cultural, economic, technological, aesthetic and environmental factors. The end result was for bioclimatic design to be applied intuitively and sustainability to be embedded in the form, configuration, construction and operational modes of farmhouses. As Cyprus attempts to conform to its EU obligations regarding the sustainable development of rural environments and make the transition towards nearly-zero energy buildings, the Cypriot vernacular farmhouse can offer valuable lessons in building design and performance, whilst provide clear guidance for its strategic restoration and reuse.

1. Introducing the Cypriot Vernacular Rural Dwelling and Farmhouse

In general, the Cypriot vernacular rural dwelling, its granary, storerooms, stables, inner courtyard and orchard functioned as a small farm. It evolved from a *monochoro* (single room) to a *makrinari* (increased longitudinal space), which gradually became the archetypal shelter of Cyprus. The need for larger and separate spaces led to the development of the *dichoro* (double-space room divided by arches or posts) and the *anoi* (upper floor). The necessity to safely store items and agricultural produce added the *sospito* (inner storage room and ground-level cellar) and the *sente* (loft for crop storage). Encouraged by mild winters yet mindful of harsh summer conditions, peasants devised courtyards and transitional spaces to create outdoor working spaces throughout the year, such as the *hliakos* (semi-open space attached to the south building façade) and the *portico* (covered street access to courtyard). These elements were widely employed throughout the island, but their size, orientation and spatial arrangement created different house forms that adapted to terrain and climate variations, inhabitant activities, household needs and socio-cultural habits associated with family and communal life [1].

Farmers' main concerns were security, longevity and survival; thus, they laid their villages cascading down mountain slopes or perched on hilltops to avoid floods and disease-ridden stagnant waters; seek protection from harsh cold winds whilst exploit cool breezes and solar radiation; and free up arable land, to be cultivated and used as pastures for their domesticated animals. Rural dwellings were tightly-clustered to form neighbourhoods around church squares and water fountains, radiating from village cores and surrounded by fertile lands, apportioned to families. Inhabitants gained communal support and established trading relationships in order to amplify production and collectively manage the community's services and resources. Each community sustained a certain autonomy out of necessity, since until the 19th century no comprehensive route network serviced the island [2]. Under heavy taxations and demand for extensive exports during the British Rule, farmers were forced to maintain high productivity, though agriculture was far from being self-sufficient and ploughing was still primitive [3]. To survive, new families built farms in the sparsely-populated village fringes. Unlike village dwellings, these farmsteads were bigger in size, consisting of the farmhouse, numerous outbuildings and larger open spaces to process and store increased amounts of agricultural produce, orchards, vegetable gardens and grazing grounds for animal herds.

2. Methodology

This research focuses on vernacular farmhouses, as part of small-scale family-owned farmsteads, instead of dwellings in densely-built rural settings. These farmhouses, as an important building type, exhibited similar but also additional building forms, spatial configurations, usages and bioclimatic strategies. Furthermore, they are still in operation, greatly supporting the primary sector of Cypriot economy. Current uses have conduced arbitrary modifications in their morphology, layout, construction and usage, which in the past had contributed positively to thermal comfort and sustainable management. In the present, unregulated modifications have caused farmhouses to become climatically inept, devoid of Bioclimatism and Sustainability. As Cyprus attempts to conform to its EU obligations regarding the sustainable development of rural environments and make the transition towards nearly-zero carbon buildings[1], the Cypriot vernacular farmhouse can provide guidelines for its strategic restoration and reuse, and in general, offer valuable lessons in bioclimatic design and sustainable performance.

Previous studies have identified the form, materiality, construction and bioclimatic strategies of traditional buildings in compact built settings [4-6]. As they examine factors separately, it is difficult to consider a potentially complex interplay of several factors related to building form, organization and usage. They also provide minimal contextualization, as they take a section across settlements to study convergent typologies and characteristics [7]. In their majority, they have produced quantifiable evidence via in-situ documentation, environmental monitoring and computer simulation, but few were supported by qualitative data [8]; and rarely did they explicitly attributed inhabitant's values, perspectives and understandings, habits and norms (socio-cultural intangible aspects), as causes to form creation, placement, layout and operational mode of vernacular dwellings. Thus, this research seeks to identify the socio-cultural, economic, technological, aesthetic and environmental factors that influence form creation, placement, orientation, spatial configuration and usage. Focusing on the relationship *"dwelling – inhabitant – environment"*, it examines how these parameters affect or relate to each other; and finally, it investigates the environmental behaviour, passive heating, cooling and ventilation strategies, as well as the sustainable operational modes of farmhouses.

In order to construct a holistic and comprehensive account of the vernacular farmhouse, this study employs multiple case studies with a fully-integrated mixed research design (QUAL+QUAN). Qualitative and quantitative methods occur concurrently in an interactive manner at all stages, so that each affects the formation of the other and leads to multi-strand directions of inquiry [9]. Data triangulation enhanced the ability of case studies to generate theory, provided additional validity to assertions made by either the researcher or the case-study participants, and maintained researcher's objectivity as cases are allowed to speak for themselves [10]. The objective of field studies is to construct life narratives for each farmhouse, informed by: inhabitants' meanings ascribed to their dwelling as a family hearth, a shelter, and an economic production unit; inhabitants' experiences, actions, uses and adaptive opportunities obtained via interviews and observed in the field, as they go about their everyday

[1] European Directive 2010/31/EE was incorporated into Cypriot legislation [Law 2012 N.210(I) /2012-5A], which stipulates that after 31/12/2020 all new and renovated buildings must be Nearly Zero Energy Buildings.

life conducting daily chores and agricultural work, and seek ways to create comfortable, liveable and functional homes. Data were collected through participant-ethnographic observation, semi-structured interviews and post-occupancy evaluation (POE) survey, and in-situ documentation with field notes, architectural drawings and audio-visual media. To assess building performance, environmental monitoring provided data for 202 days, split in five periods[2]. 12 data loggers, located in indoor and outdoor spaces most frequently used by inhabitants, recorded air temperature and relative humidity every 15 minutes. Through thematic analysis of the qualitative material [11], placement, orientation, configuration, use of spaces, construction techniques, sustainable operation and management emerge as some of the main themes. Findings from quantitative data analysis were employed to triangulate and reinforce emerging main qualitative themes.

3. Results and Discussion

3.1. Case Study (Life) Narratives

The MK, GL and EL farmsteads, built in 1949, 1935 and 1925, are located in the outskirts of a village, on a natural terrace meandering along a stream between two foothills. This region boasted most farmsteads because of its well-irrigated rich soils, accessible water bodies and natural resources, which supplied a constant source of food, clean water, fuels and supplies to be transformed into everyday tools and building materials. In the past, the inhabitants of the three case studies engaged primarily in agriculture and animal husbandry; however, in order to supplement household income, they increased functionality and diversified production by establishing light industrial facilities, arts and crafts workshops and mastering other occupations (Table 1). In the present, the MK and GL farms are still in operation though at a reduced rate. As original owners grew older, they abandoned most of their activities; and their descendants chose other occupations and migrated to near-by cities, returning to their ancestral homes to harvest, process and sell agricultural products. EL farmhouse was transformed into a vacation home, its flour mill and kiln abandoned. In all cases, changes occurred gradually as families increased and required new living spaces, either housed within or built attached to existing building cells. These modifications altered original building forms to a varying degree, created new spatial arrangements and required new apertures; however, they were based on the existing bioclimatic design, employing the same passive cooling and heating strategies. In the last decade, all three farmhouses were retrofitted with thermosiphon solar water heaters and mechanical heating and cooling systems (HVAC units, underfloor heating for MK house and electric heaters in GL and EL houses). EL house installed photovoltaic panels for its demands, the surplus sold to the electricity company.

Table 1. Case study demographics, key characteristics, occupations and activities.

C. S. Codes	No# - Gender	Age Range	Relation	Habitation Status	Owners' Occupations – Activities (Typical and representative of the region)
MK	1F- 1M	82-86	O	P	Farmer, stock breeder, agricultural produce processing, stone mason, carpenter, basket weaver, craftsman
	1F -1M	64-67	D	Oc	
GL	1F- 1M	85-89	O	P	Farmer, stock breeder, agricultural produce processing, lorry driver, tailor, textile and fabric production at the loom
	1F	47	U	P	
EL	1F -1M	92-93	O	P	Farmer, stock breeder, agricultural produce processing, bus driver, flour mill, stone quarry and lime kiln operator
	2F	50-68	D	Oc	

F= Female, M= Male, O= Owners, D= Descendants, U= Unrelated. P= Permanent, Oc= Occasional

3.2. Placement – Orientation – Configuration – Use of Spaces

In all case studies, the original farmhouse, granary and stables were located on a higher plateau within the site, further away from the street and bordering properties, in order to have an even surface onto which to build, direct rainwater run-off into the orchard, maintain dry, well-ventilated and southerly-

[2] P1: 25.12.15-11.01.16, P2: 01.05-30.05.16, P3: 11.07-21.08.16, P4: 02.09-27.10.16 and P5: 12.11-06.01.17

orientated living/working spaces and stables, and protect storerooms from damp, mould and flooding (Interviewees 3, 6 and 10). The predominant building form for a peasant's house was the *makrinari*; it was preferred not only because it was feasible, in terms of economy, practicality and availability of locally-sourced materials, but also because its shape best exploited the microclimatic conditions of the region. Based on localized wind patterns, the elongated single-spaced building and its immediate principal courtyard were orientated southeast, in order to take advantage of summer winds, sea and land breezes for passive cooling and natural ventilation, allow daylight to infiltrate the interiors and utilize passive solar heating especially in the morning during the cold months (Interviewees 2, 5 and Figure 1).

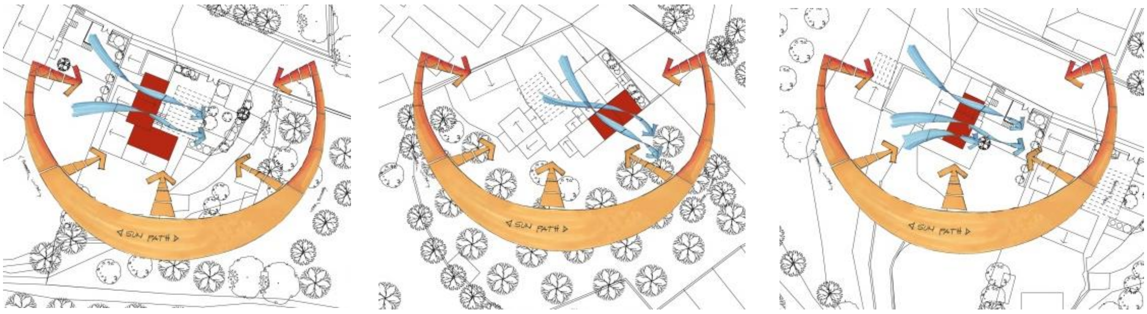
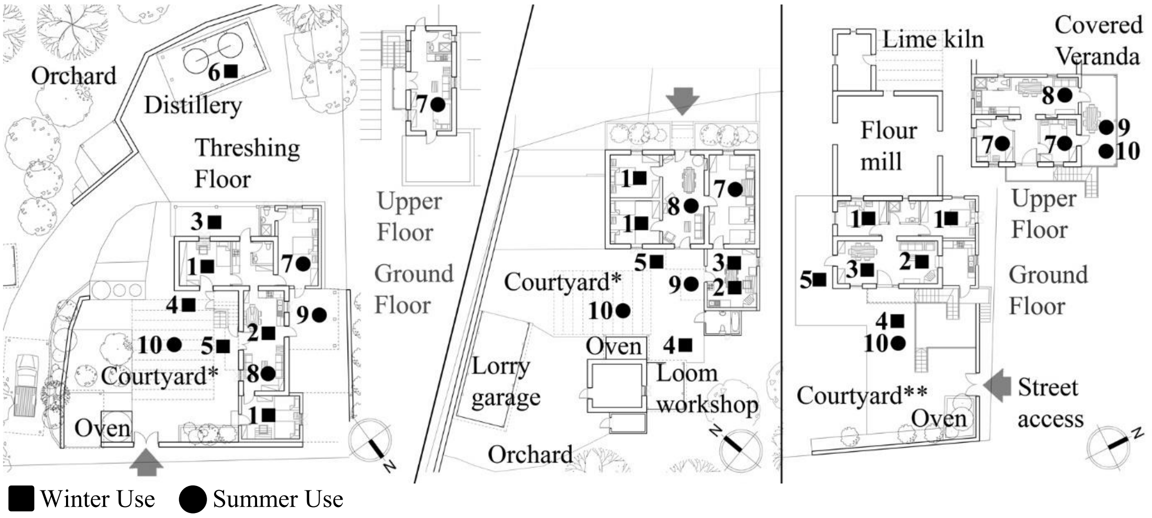


Figure 1. Placement and orientation of MK, GL and EL Farmhouses, courtyards and threshing floors, based on solar geometry and predominant summer winds. Red indicates the original *makrinari(a).*

In MK and EL farmhouses, the *makrinari* was duplicated in height so that the *katoi* functioned as a ground floor storeroom, kitchen and working area, whereas the *anoi* served as upper floor sleeping quarters. All three life narratives support that whenever inhabitants acquired economic means, they gradually added specific spaces primarily to satisfy the demands of agricultural work, e.g. a *sente* to store grains, vetch, oats and nuts, a barn to store fodder and straw, stables and a threshing floor equipped with processing equipment (i.e. grape and olive press, cisterns, distillery). Interviews revealed that traditional farmers prioritized their needs: firstly to amplify productivity and adequately store agricultural produce, and secondly to upgrade living spaces. The farming complex was enlarged not for the improvement of comfort or aesthetics, but instead, it sought to better adapt and satisfy specific needs related to the demands and necessities of agricultural life. For the Cypriot peasant, the *house* was primarily a shelter to sleep in during the cold winter nights and an enclosure to ensure family privacy, away for prying eyes; because in reality, daily life and work happened outdoors throughout the year, in open-air spaces, on flat roofs and surrounding fields. Therefore, the *house* was small enough to just fit the family, and minimal in its amenities and fixtures. It was more important to acquire and cultivate as much land as possible because it was the sufficiency of agricultural produce that provided the livelihood of peasant families (Interviewees 1, 6, 10 and Figures 1 and 2).

Studies of vernacular dwellings attest to a predominant spatial configuration: outbuildings juxtaposed in a linear fashion on each side of the farmhouse and around the courtyard. Secondary structures and open-air working spaces, perimeter walls, corrals, gardens and orchards radiated out from this centre [1]. Their siting, orientation, organization, materiality and construction techniques, heating, cooling and ventilation approaches were carefully selected for each geographic location, based on solar geometry, wind patterns, microclimate, topographical restrictions, family needs, societal structure, practical and functional requirements associated with running a farm, e.g. crop and livestock quantity and diversity, light industrial, arts and crafts activities [12]. The case studies provide evidence of the logic and intention behind these decisions. The strong bond with the land, as a principle for building form and spatial configuration, was manifested in the harmonious integration of the farming complex with its surrounding environment. The inhabitants' efforts to organise their life and work according to agricultural demands created rooms for specific use, i.e. dark, dry and cool storerooms for the preservation of foodstuff and agricultural produce, but also multi-purposed spaces to be used differently based on the agrarian calendar (interviewee 4). The need to live and work closer to nature and in accordance to the climate, manifested in open-air working and living spaces such as the courtyard, divided the farming compound into thermal zones and allowed for seasonal use of indoor and outdoor spaces: summer (cool and breezy) and winter (sun-bathed or protected) living and working quarters, sheltered stables, airy and shaded animal corrals (interviewee 9). As times changed, the family increased and required new living spaces, either housed within or built attached to existing building cells. These modifications altered original building forms to a varied degree, created new spatial arrangements and required new apertures; however they were designed in relation to the courtyard in order to contribute to natural cross ventilation, solar heating, passive cooling and night purging, and increase the existing seasonal use of spaces (interviewees 2, 9 and Figures 1 and 2).



1: Sleeping, 2: Living - cold and rainy days, 3: Working/ living - sunny days, 4: Outdoor working – morning, 5: Outdoor working – afternoon, 6: Outdoor living – evening (stills operated), 7: Sleeping, 8: Living - noontime/late evening, 9: Outdoor working – morning, 10: Outdoor working/eating/relaxing - late afternoon and evening.

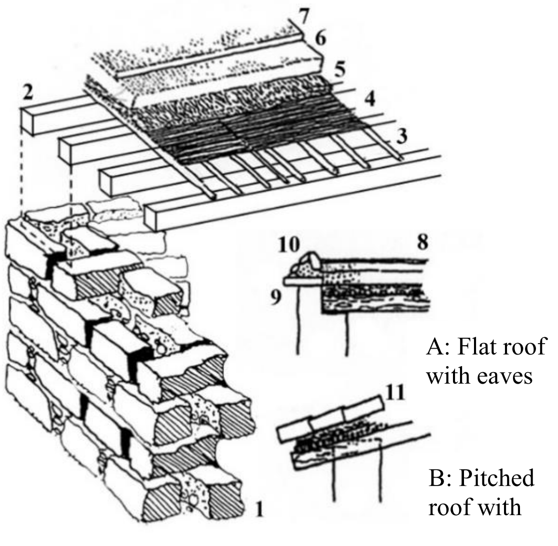
Figure 2. Seasonal spatial use in MK, GL and EL Farmhouses, based on location of fireplaces, openings, sunspots, shaded/airy outdoor areas, orientation, cross ventilation and sunlight penetration.

Field observations and inhabitant's accounts, provided evidence that the courtyard was a necessity for Cypriot peasants. Fundamentally, it functioned as a transitional space between the public community realm and the private sphere of family life. It also had a socio-cultural character: during family gatherings, coinciding with religious celebrations and agrarian cycles, extended kin and friends feasted under the shade of climbing vines in the courtyard (Interviewee 3). In terms of environmental ambience and comfort, the courtyard enabled inhabitants to conduct their chores in the open air, surrounded by nature, protected from the scorching sun but in broad daylight and in the breeze, away from the airless, smelly, gloomy and crumped indoors. During temperate weather (lasting most of the year), residents cooked and dined daily under its shade; gathered as a family; relaxed after a hard day's work; engaged in arts and crafts; took an afternoon nap, and slept during breezy nights. In winter and autumn, inhabitants preferred to sit in different spots in the courtyard (depending on the hour) to soak up the sun (interviewee 5). The courtyard, as the main living and working area, was designed with practicality, multiple functionality and flexibility to accommodate seasonal and daily household and agrarian activities. The numerous installations and equipment needed to process agricultural produce and carry out chores (e.g. fire pit, water basin and oven) were placed around its perimeter to facilitate egress, and grouped to subdivide the space into smaller sections. The olive and grape press, distillery and smoke house were similarly placed around the threshing floor, the secondary multi-purpose working area (interviewee 1). All three farmhouses were sustainably managed. Inhabitants preserved vegetables, plants, herbs and fruits for long-term consumption; processed harvested crops (grains, olives, fruits, nuts, legumes, beans etc.); and prepare dairy products and culinary delicacies (e.g. cured pork, sausages, pies and pastries). In the courtyard and the threshing floor, various agricultural produce were processed, stored, sold or traded for other necessities and precious commodities (interviewees 2, 3).

The MK farmhouse, barn and stables were organized in a Π-shape around the courtyard, so that the latter served as the main movement distributor (spaces did not communicate internally and upper floors was accessed via an open-air staircase). The building acted as a buffer against winter winds, whereas in the summer it acted as a protective barrier, stopping any by-products from agricultural activities at the threshing floor from entering indoor living spaces, e.g. winnowing of grains when winds blew from the west (interviewee 1). The courtyard exploited diurnal temperature fluctuations to become a thermal comfort regulator and microclimatic modifier, employed by indigenous builders based on amassed experience [13]. In all houses, the courtyard acted as a light well that trapped sunrays in winter when solar radiation was desirable. Its light-coloured stone paving acted as a heat sink, storing solar heat and radiating it at night. In the summer, climbing vines and trees shaded the courtyard's floor, walls and openings, thus reducing solar glare and overheating. Temperature difference underneath the vegetated canopy created a descending flow of cool air, maintaining comfortable air temperatures until the following day. The courtyard as a coolth sink, captured air movement: orientated towards summer winds, it acted as a breezeway, increasing wind speed and cooling down walls via convection. Surrounding buildings featured openings on opposite walls, so that the courtyard induced cross ventilation, fresh-air intake and passive cooling of indoor spaces (interviews, field observations).

3.3. Construction techniques and thermal inertia of building envelope

Due to scarcity of resources and transportation difficulties, peasants found materials in the vicinity of the building site. Builders prolonged the life and use of construction materials because they had knowledge for their innate properties and behaviours in response to climatic conditions, weathering and structural laws [14]. Hence, they chose specific locally-sourced and climatically- suitable materials to create air-tight and waterproofed shelters and provide certain levels of thermal comfort to inhabitants. In these farmhouses, building thermal inertia was secured by solid stone walls (thermal mass) and multi-layered roofs (high insulation). The load-bearing walls were built with coursed ashlar masonry, because sandstones and limestones could be quarried from near-by locations [15], cut into blocks and set in alternating courses, to erect an inner and an outer wall, with an overall 50-60 cm thickness (Figure 3). 'Through stones' (placed perpendicularly on both walls) were used to prevent wall delamination and crumbling. The space in-between was filled with a mixture of stone chippings, clay, straw and vinegar, in order to serve as an aggregate reinforcer to the composite double wall. Mortar, made with crushed stone powder, fly ash and clay, increased wall hydrophobicity and resistance against damp accumulation. Chamfered corner stone quoins increased aesthetics and strengthened wall junctions against earthquakes. The original buildings featured roofs composed of many layers. The width of *makrinaria* was determined by the length of tree trunks used as beams; oak, poplar and cypress were preferred, as they required minimum curing, weatherproofing and maintenance due to their high resin content. Reed wattles and dry rushes were laid on top to trap air and provide thermal insulation. Layers of reddish clay, known for its plasticity, uniformed shrinkage, fineness of grain, cohesion and hardness sealed the roof. To fortify its imperviousness and weatherproofing against possible cracking during large diurnal temperature differences, every year inhabitants added layers of packed earth, so that the rain would wash the mud into forming breaks (interviewee 3).



1: double stone walls with 'through stones', 2: timber beams, 3: pole rafters, 4: reed wattles, 5: rushes, shrubs and straw matting, 6: clay, 7: packed earth, 8: reddish clay or lime plaster, 9: stone wall plate (eave), 10: stone kerb, 11: terra cotta roof tiles or stone plates.

Figure 3. MK Farmhouse roof system and wall construction with 'through' stones and corner quoins.

The adaptive thermal comfort model [16] was used to determine indoor optimum comfort temperature (Topt comf) in a linear relationship with the exponentially weighted running mean of the daily mean outdoor air temperature (Trm), taken from MK Courtyard. Based on BS 16798-1:2019, the formula for Category III: Existing naturally-ventilated buildings with moderate expectations for thermal comfort was selected. Environmental monitoring and POE surveys showed that inhabitants were satisfied with the deliberate passive cooling, ventilation strategies and adaptive opportunities their houses provided, which combined with the thermal inertia of the building envelope, maintained indoor temperatures within the thermal comfort range for most of the year (Figure 4: Spring period). The EL living room temperature had the steadiest moving average, indicating smaller diurnal fluctuations and day-to-day changes, mainly because the farmhouse was uninhabited and no openings were operated during this monitoring period[3]. In the summer, indoor evening temperatures in all case studies remained within the comfort range. Day temperatures exceeded comfort values in MK and GL Farmhouses, except in EL residence, which was again largely unoccupied. Thus, the EL farmhouse was used to determine the dynamic effects of masonry-wall thermal mass on indoor temperatures, indicating a time lag of approximately four hours; and confirmed that the multi-layered roofing system offered protection against temperature extremes and intense insolation, keeping indoor temperatures at comfortable levels even during hotter months and reducing winter conventional heating loads, which is in accordance to recent studies [7, 17]. Field observations and POE surveys attested that due to the nature of their daily chores, inhabitants lived outdoors, preferring to work in shaded corners and breezeways in the courtyard. In the summer, they opened all apertures to induce air currents from and to internal and external spaces and dissipate heat build-up, in preparation for evening indoor living, instead of turning on mechanical cooling. They operated mechanical heating and fireplaces during winter, as the building envelope could not maintain satisfactory thermal comfort levels.

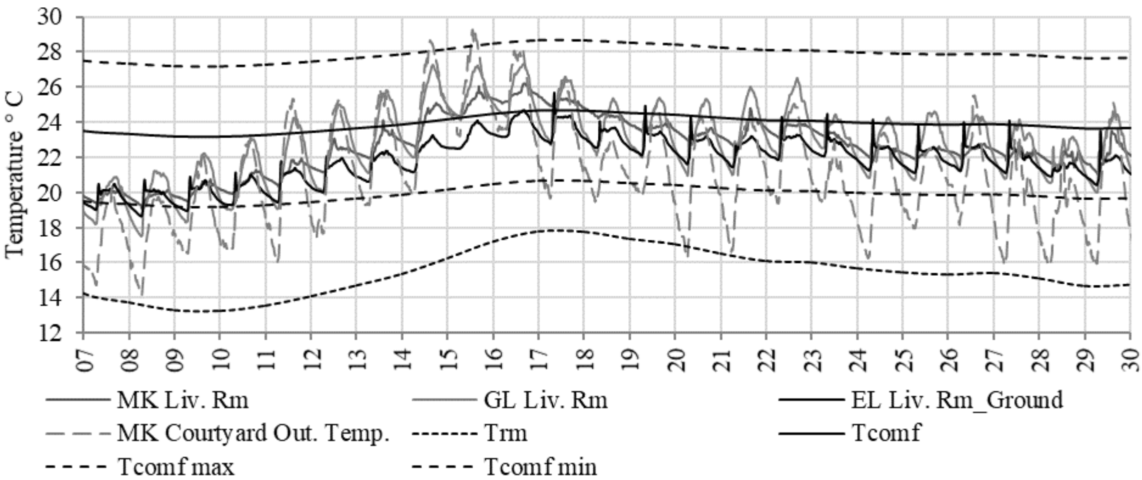


Figure 4. Living room indoor versus outdoor temperatures, Trm and Tcomf, during 07-30.05.2016.

3.4. Sustainable Management

In terms of waste management, they recycled and reused everything, from broken items transformed into tools, to multi-purposed apparatuses and riggings. At the garbage site, fruit and vegetable peels and grape pomace were mixed with fodder as livestock feed, or decomposed and mixed with manure to make a richer fertilizer. Women collected water from wells and streams, and harvested rainwater from tiled roofs to store in reservoirs (interviewees 5, 9). Mustard greens, pumpkin vines, sunflowers, mulberry, poplar and eucalyptus trees were planted near outhouses and stagnant waters to decontaminate the soil as biological hydraulic containment systems, contaminant root up-takers, stimulators and hyperaccumulators. Wild grasses and clover thrived in the orchard as stabilizers and as fresh food for animals. Farmers, equipped with an in-depth knowledge of botany, cultivated herbs as medicines, food flavouring agents, preservatives and natural repellents (interviewees 4 and 11). Nut and fruit trees and

[3] EL living room: mean Diurnal Temperature Difference (DTD) = 2.2 ºC, StD= 0.84 ºC, Diurnal Temp. Range (DTR) = 18.6-25.8 ºC (abs. max-abs. min. temp.). Outdoor Temp.: mean DTD = 6.5 ºC and DTR = 14-29.2 ºC.

sycamores for in-house sericulture were planted in the orchard. Rotational crop management of vegetables increased crop yield, replenished nutrients, improved soil structure, reduced erosion and pollution, controlled pest infestation and diseases, and reduced stress of weeds (interviewees 3 and 6).

4. Conclusions

The adaptive building form and spatial configuration of Cypriot vernacular farmhouses and their compounds evolved by correlating microclimatic and environmental characteristics, socio-cultural needs related to family and communal life, material scarcity and construction limitations, practical and functional farming requirements. Each indoor and outdoor space acquired multiple functionality and usage, certain materiality, design, placement and orientation in order to: fortify each other to optimize building performance, quality and comfort; offer thermal diversity and adaptive opportunities to occupants; and allow for a more feasible management. Economic viability necessitated these practices; but it was the strong relationship between the inhabitants, their dwelling and the environment, ingrained by tradition, accumulated knowledge and tried experience that led to the intuitive application of passive heating and cooling strategies and sustainable operational modes. The three case studies, as examples of modified and current use, support that if similar vernacular farmsteads are restored and reused based on their embedded bioclimatic design, they can reduce heating and cooling demands on mechanical heating and cooling systems. Solar water heaters and renewable energy systems can be installed either on their roofs (as they are properly oriented) or in their larger plots, to satisfy electricity requirements and provide a constant supply of hot water. Since most of them have wells and harvest rainwater, they can operate small water-treatment facilities for irrigation and animal watering. They can also increase their productivity and profits, by utilizing their existing resource and waste management and seasonal crop rotation practices. As costs for new construction are increasing, due to the fast transition towards zero carbon buildings, these retrofitted and upgraded vernacular buildings and sustainable farms offer more viable solutions, especially to low-income working families, and provide employment alternatives in the primary sector of the Cypriot economy.

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